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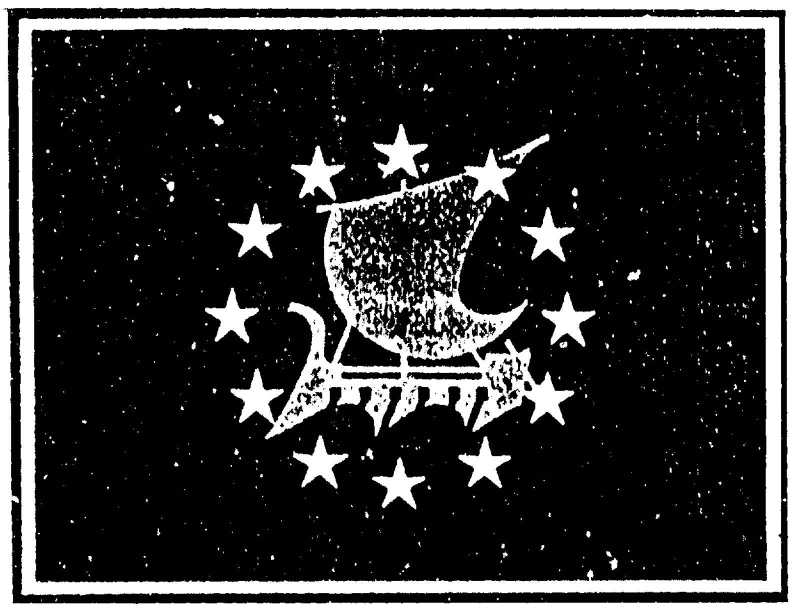

ELSEVIER APPLIED SCIENCE

APPLICATION OF THE OPERATOR EXPANSION METHOD TO REALISTIC TWO-DIMENSIONAL (2D) SEA SURFACES

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SUMMARY

The operator expansion method has been shown to model quickly and accurately acoustic scattering from surfaces with roughness similar to that of the oceans. In this paper, the monostatic backscatter is computed using the operator expansion method over an ensemble of modeled 2D deterministic sea surfaces. In particular, low grazing angle azimuthal dependence of the backscatter is explored.

1. INTRODUCTION

The operator expansion method for quickly solving the Helmholtz Integral Equation for the scattered field was outlined by Milder[1]. This method finds the scattered fields at an interface by a Taylor series approximation with respect to the surface height based on the filtered FFT of the incident fields. Since the operator expansion method is driven by FFTs rather than by either direct or indirect matrix inversion, it is much quicker than exact integral equation methods. Furthermore as the number of field points increases, the calculation time increases at a much slower rate for the operator expansion method than with the exact integral equation methods. The operator expansion method has also been shown to be sufficiently accurate for regime of interest here. Kaczkowski and Thorsos demonstrated that this method spans the regimes of validity of both the Kirchhoff and small perturbation approximation[2]. Further confirmation by the authors[3] has shown that third order and higher terms of the symmetric operator expansion are unnecessary for modeling rough sea surfaces reflection for the source frequency range considered. Here we will show the average monostatic backscattering from rough surfaces representative of a surface wave spectrum encountered in the Gulf of Alaska without any consideration of possible bubble fields. Our goal in accomplishing this is three fold. 1) We wish to show that a wide range of scattering problem that were previously too large to compute can now be solved. 2) We hope to gain some sort of insight into the scattering behavior of two dimensional random surface fields. 3) By examining simulated sea surface scattering without a consideration of bubble fields, we wish to learn more about the contributions to observed sea scattering made by both surface scatting and bubble scattering.

2. SPECTRUM AND SURFACE GENERATION

If a survey of the literature were conducted on the subject of modeling the acoustic scattering from the sea surface roughness, it would reveal that almost all of the analysis to date involves surface spectra due to temporally-stationary, spatially-uniform forcing conditions. If two-dimensional (2D) sea surfaces are considered, a simple azimuthal dependence, perhaps not even wavenumber dependent, is typically assumed. In reality, the sea surface is influenced by nearby as well as distant forcing phenomena, evolving over time in a complex manner. In order to examine acoustic scattering from sea surfaces that are due to temporally non-stationary, spatially non-uniform generating winds, i.e., more realistic sea surfaces, the DWAVE Model has been employed. This model[4] numerically calculates the directional wave spectrum at a given geographical location based on the time-varying wind field and other environmental information specified over an extended region. This 2D numerical spectrum is then used in the filtering process that is described below in order to generate ensembles of scattering surfaces.

The particular spectrum considered in this paper occurred during the spring of 1990 in the Gulf of Alaska. During the hours prior to this event, winds in the area ranged from 8-15 m/s. The rms. roughness of the seas was .296 meters at this time. A contour plot of the surface roughness spectrum is shown in figure 1. In order to generate realizations having this spectrum, a 2D field of Gaussian deviates, were Fourier transformed, filtered in the transform domain, and inverse transformed. In this way, the 2D array of random surface heights are correlated to have the desired roughness spectrum. For the cases considered herein, the surface spectrum was sampled 512 times in both the k_x and k_y at a rate of $\Delta k_x = \Delta k_y = .04$ rad/m. This resulted in realizations defined at intervals

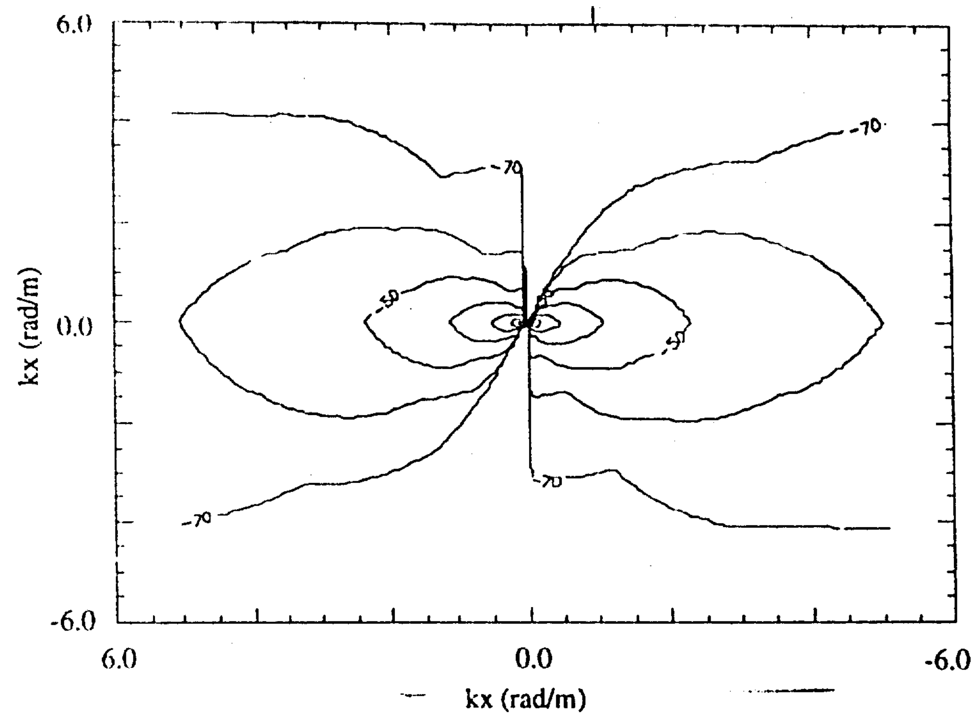

Figure 1 Logarithmic contour plot of the chosen sea surface roughness spectrum.

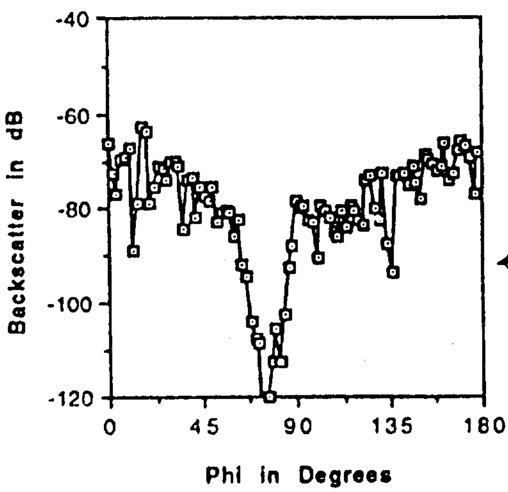

Figure 2. Backscatter intensity plot versus azimuth for the surface shown in figure 2.

Figure 3. 50 by 50 point sample of the first surface realization of the ensemble.

$\Delta x = \Delta y = .307$ and covering an area of nearly 25,000 square meters. For the calculation of the statistics of the scattered field 50 sea surface realizations were used.

3. NUMERICAL RESULTS

For this data set we examined the azimuthal(ϕ) dependence of the monostatic backscatter. Holding the incident grazing angle θ^{inc} fixed at ten degrees backscatter was calculated for every two degrees in azimuth. The 250 Hz incident pressure wave fields calculated at each sample point for each incident phi were:

$$p^{inc}(r) = \exp[-ik \cdot r - \frac{4((x^2 + y^2)^{1/2} - z\cot(\theta^{inc}))}{L}]$$

Where L = the surface sample's extent in the x and y directions, the wavelength is 6 meters, and the origin is set at the center of the surface sample. Backscatter in dB is calculated relative to the far field scattering intensity given by a scatterer that is non directional in phi plane of incidence. This can be expressed formulaically in the following way:

$$P^{\phi\theta} = \frac{m \sum_{i=1}^{n} P_i^s e^{-ik_{\phi\theta} r_i}}{\sum_{j=1}^{m} \sum_{l=1}^{n} P_l^s e^{-ik_{\phi\theta} r_l}}$$

Where $P^{\phi\theta}$ is the far field normalized pressure field in the given direction, P^S is the pressure at each of the n surface points, and m is the number of theta samples taken in the phi plane. Figure 2 shows the backscatter of the above acoustic beams from a single surface realization which has been partially illustrated in Figure 3. Figure 4 shows the average backscatter in phi for the 50 surface ensemble as well as the 90% confidence range in dB. Calculated but not shown is the perturbation theory results for the same spectrum. Perturbation theory, though lacking details, gives the same general shape in azimuth. In particular the null around 90 degrees in azimuth in figure 6 is in agreement with first order perturbation theory. All the above calculations were performed on a Cray Research Corporation Y-MP eight vector processing supercomputer.

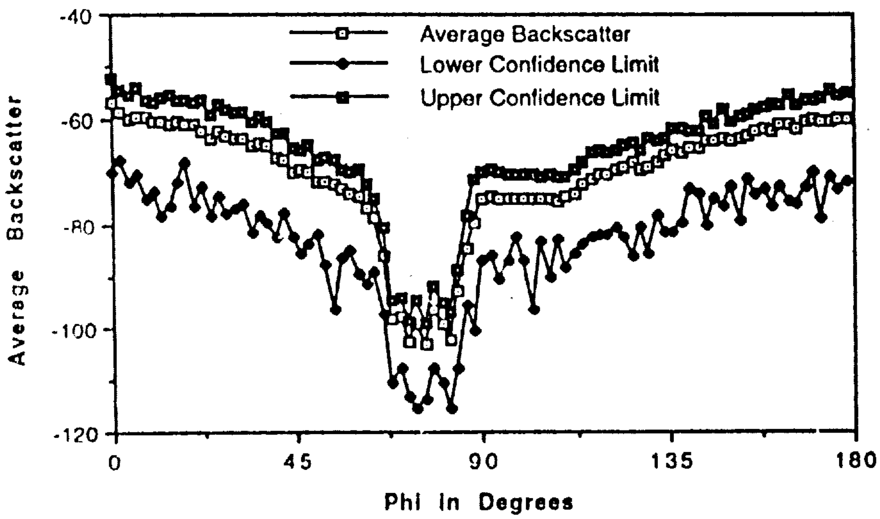

Figure 4. Average Backscatter of 50 element ensemble of surface realizations of the spectrum in figure 2. Backscatter given in dB relative to isotropic scattering.

4. CONCLUSIONS

The symmetric operator expansion enables one to quickly calculate the acoustical energy surface scattering with less than one part in a thousand error for surfaces too large to compute using other similarly accurate methods. For example a single backscatter geometry takes approximately 45 seconds to solve using the operator expansion method versus over a hundred days for a similarly accurate Iterative Moment Method solution for the same geometry. Furthermore, while the Perturbation Theory method produces a quick look at the approximate ensemble average backscatter from a given surface wave spectrum, the symmetric operator expansion method has the advantages over Perturbation Theory that all scattering geometries in the half space can be calculated, non-plane wave incident fields can be introduced, more statistical data can be produced, and grater accuracy can be achieved.

These calculations show a strong dependency of the backscatter intensity on the azimuthal angle for all surfaces generated in the data set.. This dependency is also visible in all other calculations performed on modeled Gulf of Alaska surface spectra. This observation implies that the rough surface backscatter status as either possibly contributory or non-contributory to measured ocean backscatter depending on whether a measured phi angular backscatter dependence is respectively found or not found. Unfortunately, there is no published data found by the authors that conclusively answers this question. Hopefully experiments will be performed or data will be published that could conclusively answer this question.

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